

LONDON- WEST MIDLANDS ENVIRONMENTAL STATEMENT

Volume 5 | Technical Appendices

CFA15 | Greatworth to Lower Boddington
Culworth Brook at Lower Thorpe modelling report
(WR-004-006)
Water resources

November 2013

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Department
for Transport

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1 Introduction

1.1 Structure of the water resources and flood risk assessment appendices

1.1.1 The water resources and flood risk assessment appendices comprise six parts. The first of these is a route-wide appendix (Volume 5: Appendix WR-001-000).

1.1.2 Specific appendices for each community forum area (CFA) are also provided. For the Greatworth to Lower Boddington area (CFA15) these are:

- a water resources assessment (Volume 5: Appendix WR-002-015);
- a flood risk assessment (Volume 5: Appendix WR-003-015); and
- hydraulic modelling reports for the Culworth Brook at Lower Thorpe (i.e. this appendix), River Cherwell at Edgcote (Volume 5: Appendix WR-004-007), and the Highfurlong Brook (Volume 5: Appendix WR-004-008).

1.1.3 Maps referred to throughout the water resources and flood risk assessment appendices are contained in the Volume 5, Water Resources and Flood Risk Assessment Map Book.

1.2 Scope and structure of this assessment

1.2.1 This document presents the hydraulic modelling that was undertaken for the Culworth Brook at Lower Thorpe. The purpose of the modelling is to supplement the baseline flood risk datasets upstream of the proposed crossing to support the flood risk assessment.

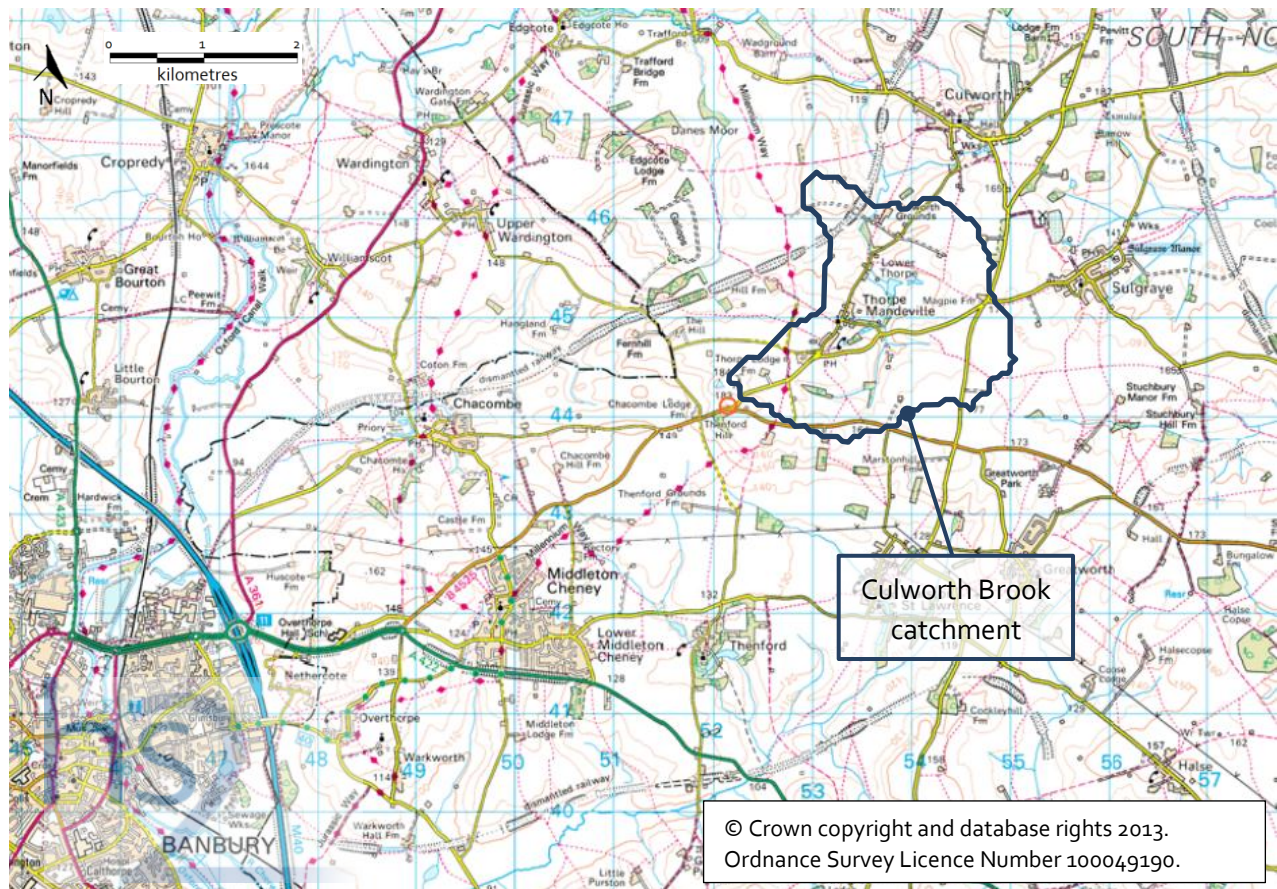
1.2.2 The catchment hydrology is reported in Section 2. Flood water levels, depths and floodplain extents are reported for the baseline in Section 3. Section 4 includes conclusions and recommendations, and Section 5 covers assumptions and limitations of the hydrology and hydraulic modelling.

2 Hydrology

2.1 Location and topography

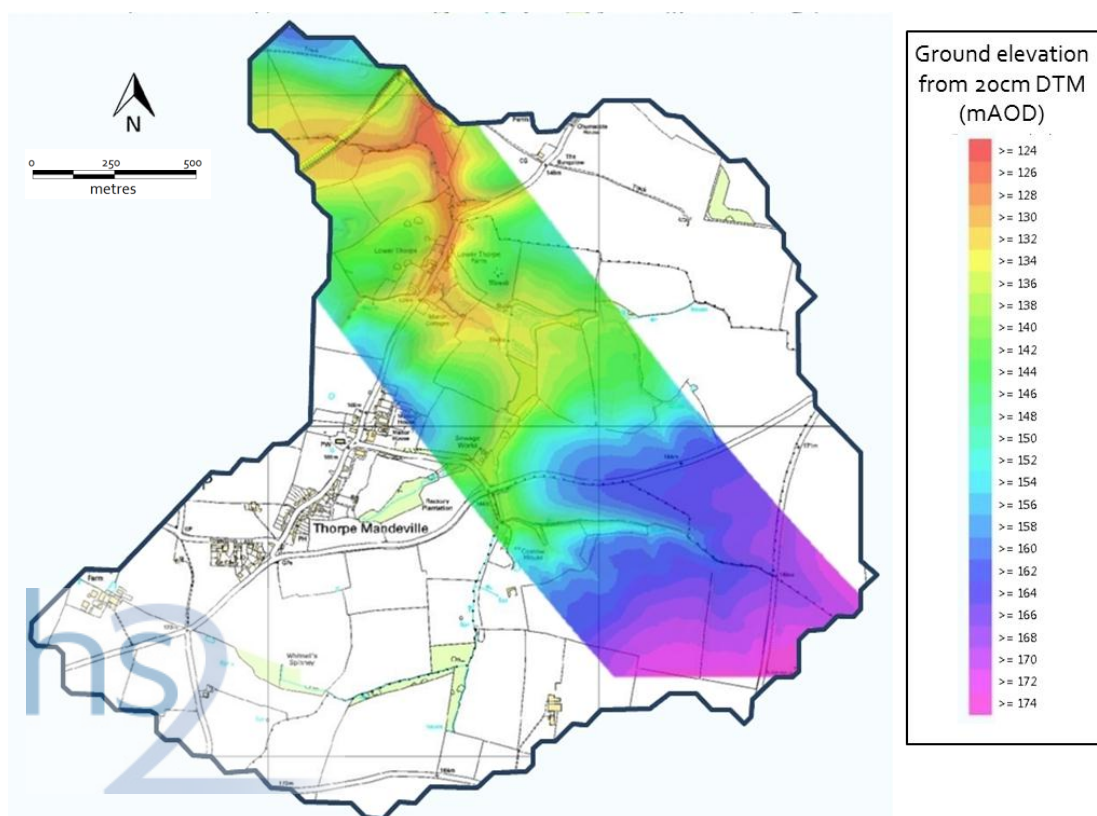
- 2.1.1 The study catchment is within the upper reaches of the Culworth Brook and lies to the north-east of Banbury in Northamptonshire, as shown in Figure 1. The Culworth Brook is a tributary of the River Cherwell, with its confluence to the east of Trafford Bridge. The downstream boundary of the study catchment has been chosen as the culvert beneath the access track to the west of Culworth Grounds Farm.

Figure 1: Location of the catchment of the Culworth Brook



- 2.1.2 The catchment of the Culworth Brook contains the villages of Thorpe Mandeville and Lower Thorpe. The topography of the catchment is fairly steep with ground levels ranging from around 175m above Ordnance Datum (AOD) in the south to 124m AOD at the downstream boundary where demonstrated by light detection and ranging (LiDAR) information, as shown in Figure 2. There are historical farm workings in a number of the fields, with ridge and furrow patterns visible in the 20cm digital terrain model (DTM). There are some public highways and a disused railway line that are shown to have associated earthworks that have changed the natural topography. In addition, an artificial pond was created at the historical confluence of a tributary of the Culworth Brook at the centre of the catchment which involved the construction of an earth dam.

Figure 2: Topography of the Culworth Brook catchment



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2.2 Hydrological context

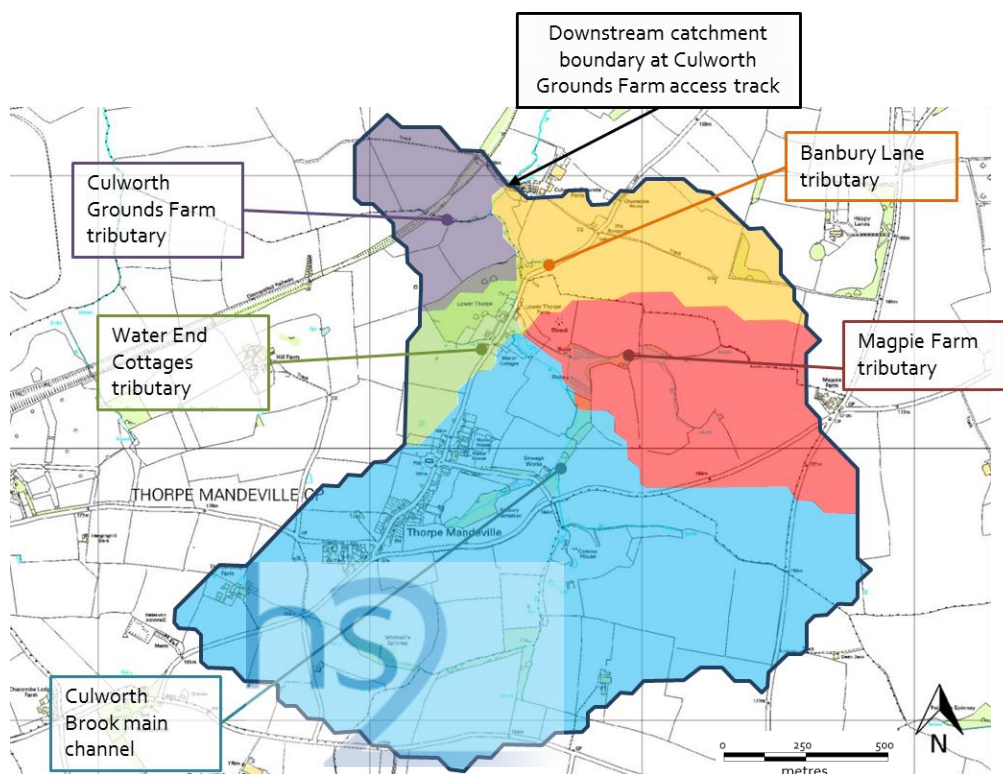
- 2.2.1 The Culworth Brook has a catchment size of 4km² at the culvert beneath the access track to Culworth Grounds Farm, the location of which is identified in Figure 3. Catchment descriptors have been obtained from the Flood Estimation Handbook (FEH) CD-ROM (v3). The catchment is relatively shallow (index of catchment steepness (DSPBAR) = 48.8) for a headwater catchment, with the longest drainage path of 3.75km and low aspect variation (0.26) suggesting narrow, relatively straight, valleys. The average drainage path length of 1.97km suggests that the catchment is fairly uniform in width along its length.
- 2.2.2 The climate and soils descriptors show that the catchment is relatively dry, with low annual rainfall (standard average annual rainfall (SAAR) = 682mm) and a low proportion of time annually where soils are 'wet' (index of proportion of time soils are wet (PROPWET) = 0.3). Attenuation is present within the catchment due to reservoirs or lakes (flood attenuation due to reservoirs and lakes (FARL) = 0.957).
- 2.2.3 The catchment is 'essentially rural' with an urban extent value (in the year 2000) of 0.0094, comprising properties at Lower Thorpe and Thorpe Mandeville.
- 2.2.4 The natural catchment is composed of two primary watercourse inflows, which converge at Lower Thorpe:

- the Culworth Brook main channel (shaded blue in Figure 3) originates at Costow House to the east of Thorpe Mandeville. The watercourse enters the study area at Thorpe Mandeville Sewage Treatment Works. The design catchment for this watercourse is taken at the confluence of the lateral inflow at Water End Cottages, Lower Thorpe; and
- the tributary from Magpie Farm (shaded red in Figure 3) flows through a number of ponds prior to a confluence with the main Culworth Brook in Lower Thorpe. The design catchment for this watercourse is taken at the confluence with the Culworth Brook.

2.2.5 There are a further three smaller sub-catchments from local streams:

- the tributary at Water End Cottages in Lower Thorpe (shaded green in Figure 3) rises west of Lower Thorpe and joins the Culworth Brook close to Water End Cottages in Lower Thorpe. The design catchment for this inflow is taken at the confluence with the Culworth Brook;
- the tributary from Banbury Lane (shaded orange in Figure 3) rises from the carriageway of Banbury Lane and flows for a short distance before its confluence with the Culworth Brook. The design catchment for this inflow is taken at the confluence with the Culworth Brook; and
- the tributary at Culworth Grounds Farm (shaded purple in Figure 3) rises to the west of the disused railway line to the west of Culworth Grounds Farm and flows for a short distance before its confluence with the Culworth Brook. The design catchment for this inflow is taken at the confluence with the Culworth Brook.

Figure 3: Culworth Brook sub-catchments to Culworth Grounds Farm



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- 2.2.6 The catchments of the lateral inflows have been checked to ensure that the combined area corresponds to the total area at the downstream boundary.

2.3 Hydraulic connectivity

- 2.3.1 A site familiarisation visit was undertaken in December 2012 to the watercourses at Lower Thorpe.
- 2.3.2 Modifications have been made to the channel along this reach. Just downstream of Thorpe Mandeville Sewage Treatment Works there is a 2m high dam (locally known as 'Giants Grave') across the watercourse that was identified in a 1982 assessment of historical monuments in Northamptonshire¹ as a medieval fish pond, identified as location six in Figure 4. The pond has subsequently (prior to 1802) ceased to be used and a gap has been made in the dam for flows in the Culworth Brook to pass. From here the watercourse does not follow the valley floor and instead follows a straightened path to the north-west.

Figure 4: Historical assessment of the ponds at Lower Thorpe



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¹ English Heritage (1982), *Thorpe Mandeville, An Inventory of the Historical Monuments in the County of Northamptonshire, Volume 4: Archaeological sites in South-West Northamptonshire* (1982), pp. 145-148. URL: <http://www.british-history.ac.uk/report.aspx?compid=126588> Accessed: August 2013

- 2.3.3 Historically, the Magpie Farm tributary would have joined the Culworth Brook approximately 200m to the south-west of the properties in Lower Thorpe. However, a series of ponds have been created that artificially alter the hydraulic connectivity for this tributary. The Magpie Farm tributary flows through two smaller ponds before entering a larger pond (hereby referred to as 'the large pond') that has an embankment on its western boundary, identified as location seven in Figure 4. The historical assessment undertaken in 1982 concluded that these ponds, "appear to be of post-medieval date, probably of the 18th century, and were perhaps used for breeding wildfowl and for boating". The large pond has a number of linear islands that are heavily vegetated.
- 2.3.4 The outfall from this system of lakes is to an artificial leat² (hereby referred to as 'the leat') that historically fed a mill in Lower Thorpe. The structure at this outfall was found to be a makeshift weir made of wooden stakes, boards and branches. The structure is shown in Figure 5 looking upstream with the outfall to the leat in the foreground and the large pond in the background.

Figure 5: Weir structure at outfall of large pond



- 2.3.5 The leat continues with a fairly shallow gradient towards a network of ponds close to Lower Thorpe that are believed to be part of the historical mill workings. The Environment Agency Detailed River Network (DRN) shows the leat to be hydraulically connected to the main channel of the Culworth Brook downstream of the culvert beneath Banbury Lane. Following a review of the topography and Ordnance Survey (OS) mapping, however, it is not clear whether there is a connection beneath the road.

² A leat is a local reference to a small watercourse that was artificially created to transfer water, predominantly to a mill.

Instead, it has been assumed that flow within the leat enters the ponds and flows in a southerly direction towards the main channel.

- 2.3.6 At the south western corner of the large pond there is a sluice structure on the main the channel of the Culworth Brook, shown in Figure 6. During the site visit there appeared to be hydraulic connectivity between the main channel and the large pond, perhaps through a short culvert. The head difference upstream and downstream of the sluice structure was approximately 1m.

Figure 6: Sluice structure on main channel of Culworth Brook at south-western corner of large pond looking upstream



- 2.3.7 The main channel continues downstream, through at least one culvert for a farm access track, until Banbury Lane, where it is shown on OS maps to enter a culvert beneath the road. The diameter of the culvert is not known.
- 2.3.8 Downstream of Banbury Lane the Culworth Brook returns to a more natural profile. The Culworth Grounds Farm tributary was included in the site familiarisation visit, as was the chosen downstream boundary of the catchment at the access road to Culworth Grounds Farm where there is an existing culvert.

2.4 Hydrological assessment

- 2.4.1 An initial hydrological assessment was undertaken across the entire Culworth Brook catchment to the downstream boundary at Culworth Grounds Farm to determine likely peak flows within the watercourse, and to assess the performance of the two main flood estimation procedures in relation to one another. A full routed rainfall-runoff output such as that derived using the Revitalised Flood Hydrograph (ReFH) rainfall-runoff methodology is required for time-varying hydrodynamic modelling.

Revitalised Flood Hydrograph rainfall runoff method

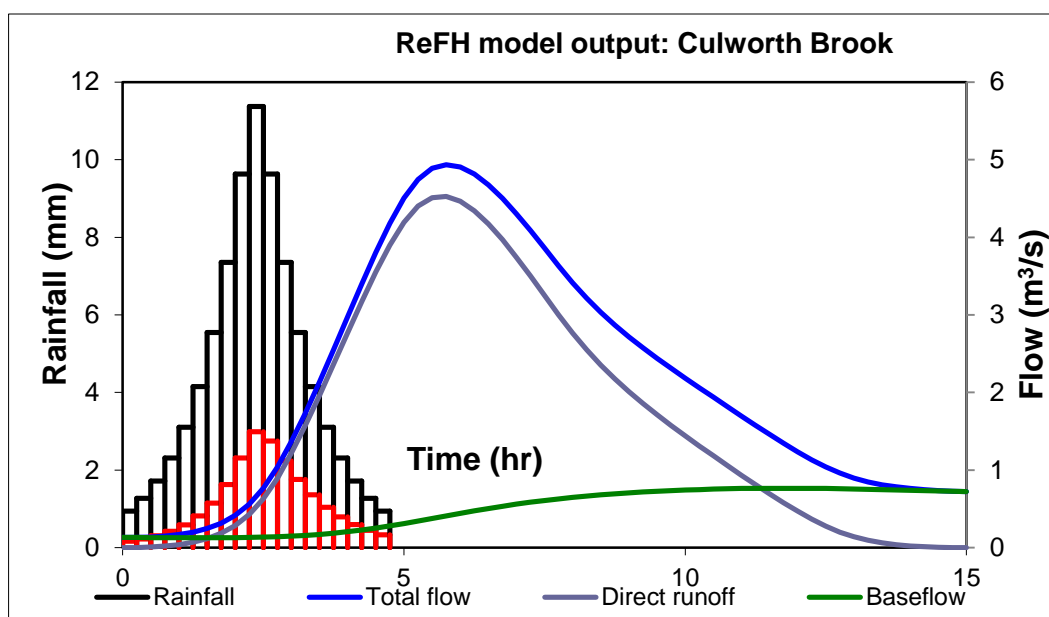
- 2.4.2 The ReFH rainfall runoff method was applied, using the spreadsheet implementation (v1.4) provided by HR Wallingford, together with the catchment descriptors obtained from the FEH CD-ROM (v3). No rainfall or flow data was available for the catchment, and all ReFH design standard parameters were therefore applied without observed or analogue adjustments. A model timestep of 15mins and storm duration of 4.75hrs were used in the analysis.
- 2.4.3 The FEH depth-duration-frequency rainfall modelling for the catchment was used to obtain total rainfall volumes for each design storm, which was spread across the chosen storm duration using the winter storm profile, due to the rural nature of the catchment. Seasonal correction and areal reduction factors of 0.67 and 0.96 were applied, with resultant total and peak storm rainfall as shown in Table 1.
- 2.4.4 The loss, routing and baseflow models use the catchment descriptors and standard ReFH models and parameters in the absence of any gauged flow information for the watercourse. The unit hydrograph time to peak of 2.5hrs indicates a relatively fast flood response for the catchment size. Calculated initial baseflows are very low, at approximately $0.13\text{m}^3/\text{s}$. An initial soil moisture deficit of 113mm was calculated. The combined models were applied to the calculated input rainfall by scaling and aggregating the unit hydrograph calculated using the loss and routing models. The baseflow hydrograph was then combined with the storm hydrograph to give a design hydrograph for each return period.

Table 1: Culworth Brook ReFH rainfall volumes and peak flows

Return period	Depth-duration-frequency rainfall (mm)	Design rainfall (mm)	Peak rainfall (mm)	Peak runoff (m^3/s)
20 years	45.8	29.7	4.1	1.8
100 years	70.3	45.6	6.2	2.6
1,000 years	128.6	83.4	11.4	4.9

- 2.4.5 The 100 year return period rainfall event results in a peak runoff rate of $2.6\text{m}^3/\text{s}$. The rainfall hyetograph and corresponding fluvial flood hydrograph are presented in Figure 7.

Figure 7: Culworth Brook ReFH hydrograph for the 100 year return period event



Modelled sub-catchment inflows

- 2.4.6 Due to the four separate inflows into the Culworth Brook within the study area (as described in Section 2.2 of this report) in order to accurately model the watercourse, each sub-catchment inflow must be applied separately at the relevant boundary inflow location. Consequently, it is necessary to divide the catchment into the component parts to obtain each separate inflow.
- 2.4.7 The catchment descriptors for each sub-catchment were extracted by adding, or subtracting, component parts using the FEH CD-ROM to extract intermediate catchment characteristics along the watercourse. Area-weighted averages, or specific adjustment procedures as detailed in the FEH volume 5³, were used to create catchment descriptor files for each of the five component catchments, as presented in Table 2.
- 2.4.8 Each modified catchment descriptor file was imported directly into the hydraulic model and applied to the relevant boundary locations to enable calculation of the relevant runoff modelling parameters at each inflow.

³ Institute of Hydrology (1999), *Flood Estimation Handbook*.

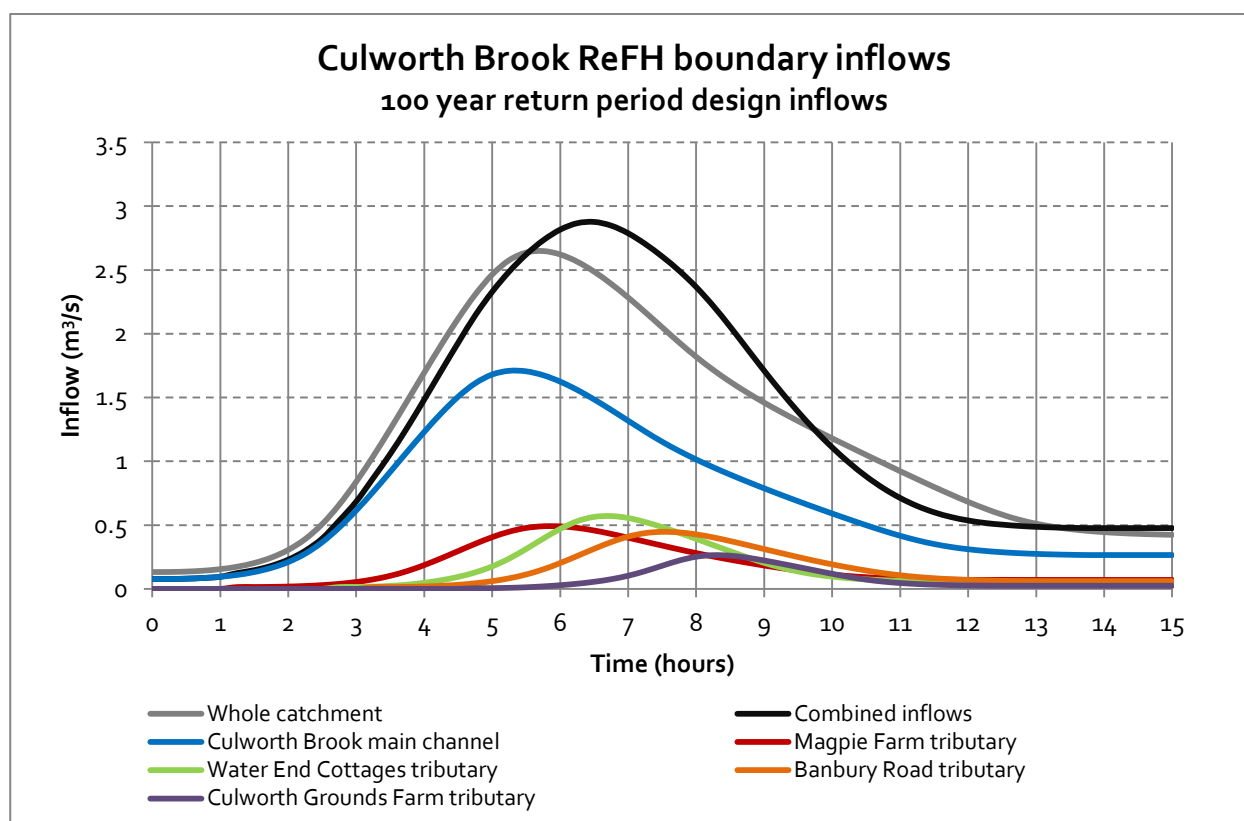
Table 2: Key model catchment descriptors for the Culworth Brook and its five sub-catchments

Model catchment descriptors	Culworth Brook (direct, total catchment)	Culworth Brook main channel (direct)	Magpie Farm tributary (derived)	Water End Cottages tributary (derived)	Banbury Road tributary (derived)	Culworth Grounds Farm tributary (derived)
AREA	4.02	2.38	0.7	0.13	0.47	0.34
BFIHOST	0.56	0.57	0.64	0.39	0.58	0.41
DPLBAR	1.97	1.53	0.84	0.33	0.66	0.55
DPSBAR	48.8	42.7	48	78.36	52.35	76.94
FARL	0.98	1	0.78	1	1	1
FPEXT	0.022	0.032	0.018	-0.0014	0.00058	0.00015
FPDBAR	0.18	0.2	0.075	0.00023	0.0018	0.0038
PROPWET	0.3	0.3	0.3	0.3	0.3	0.3
SAAR	682	683	683	683	675.17	682
SPRHOST	31.77	31.94	25.97	42.11	29.64	41.51
URBEXT ₂₀₀₀	0.0094	0.015	0	0.02	-0.000045	0.00074

2.4.9 When modelling a small catchment with a variety of inflows, it is reasonable to assume that each catchment will experience the same rainfall intensity, rather than each being subject to the calculated critical storm for each inflow, which could vary widely between catchments. In this case, the critical storm calculated for the full catchment to the railway crossing has therefore been applied to each inflow catchment, with the ReFH routing model used to determine peak river flows. Due to the compact nature of the overall catchment, the whole catchment is modelled to experience the same storm simultaneously.

2.4.10 Each sub-catchment inflow was extracted from the hydraulic model in order to verify the approach previously described. Inflow hydrographs were extracted for the 100 year design rainfall event, and combined to create an instantaneous inflow hydrograph. The time to peak varied for each of the tributary catchments. The inflows from each of the tributaries were lagged in an attempt to obtain a hydrograph with an equivalent time to peak and peak flow to the whole catchment hydrograph, as presented in Figure 8. The peak instantaneous inflow was found to be 2.88m³/s, which corresponds well with the peak flows calculated for the entire catchment.

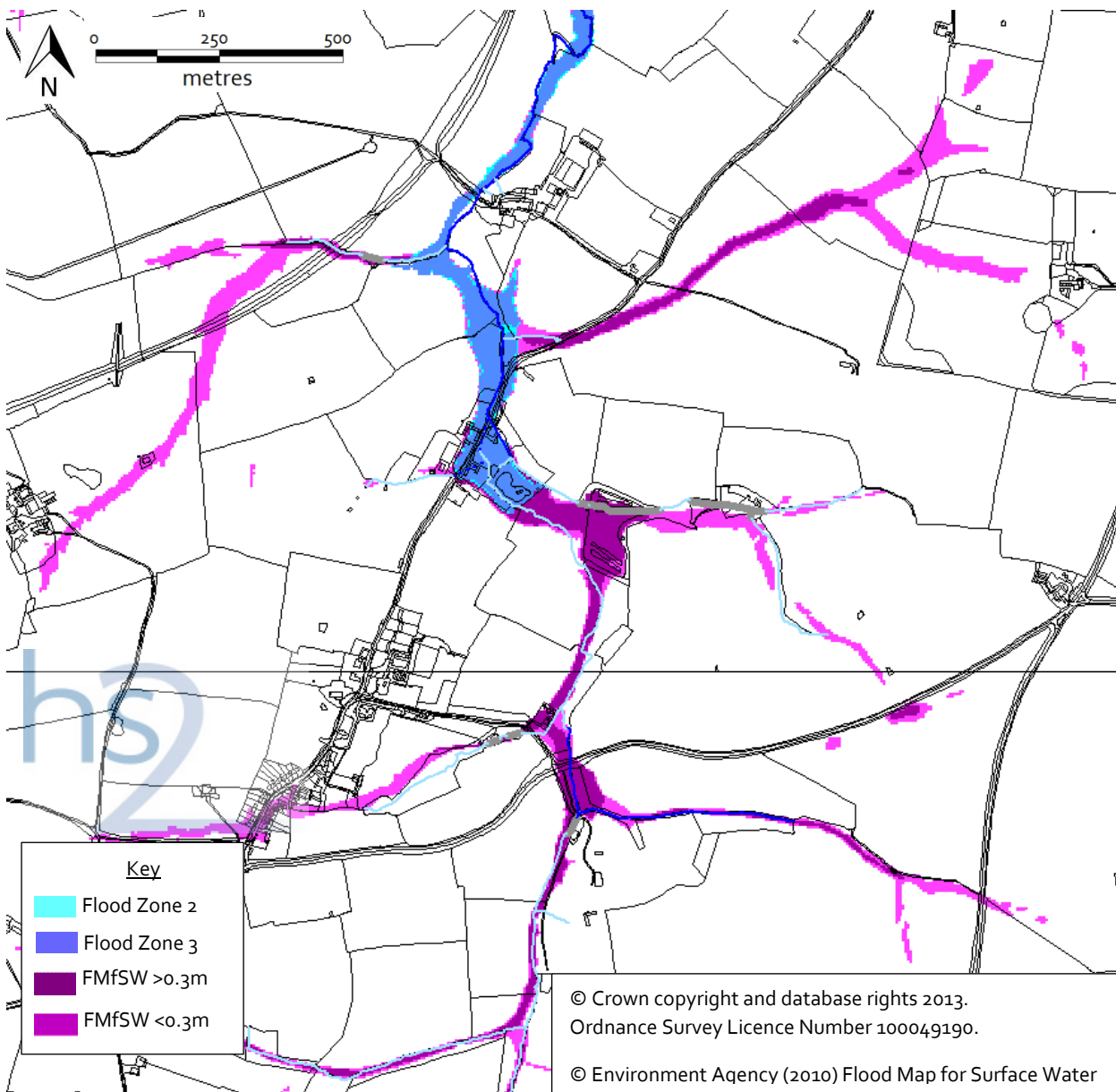
Figure 8: Culworth Brook ReFH inflows for the 100 year design rainfall



2.5 Existing flood risk datasets

- 2.5.1 Previous hydraulic modelling has not been undertaken for this reach of the Culworth Brook. Environment Agency Flood Zones are based on the national modelling and therefore do not take into account complex hydraulics such as embankments and culverts, as shown in Figure 9. The Flood Zone Maps commence where the upstream catchment area is greater than 3km². There are no flood zones defined for the upper half of this catchment as the catchment area is less than 3km².
- 2.5.2 The Environment Agency Flood Map for Surface Water (FMfSW), also shown in Figure 9, increases the upstream extent of predicted flooding for the Culworth Brook and its tributaries. The predicted surface water flowpaths generally follow the lowest point of the valley; the section between Thorpe Mandeville Sewage Treatment Works and the large pond, however, is to the west of the valley bottom and is therefore not consistent with the ground profile. Hydraulic modelling has therefore been undertaken in this location to confirm the existing extent of flooding.

Figure 9: Environment Agency Flood Zone Map and Flood Map for Surface Water 1 in 200 years return period (0.5% annual probability) rainfall event for the Culworth Brook

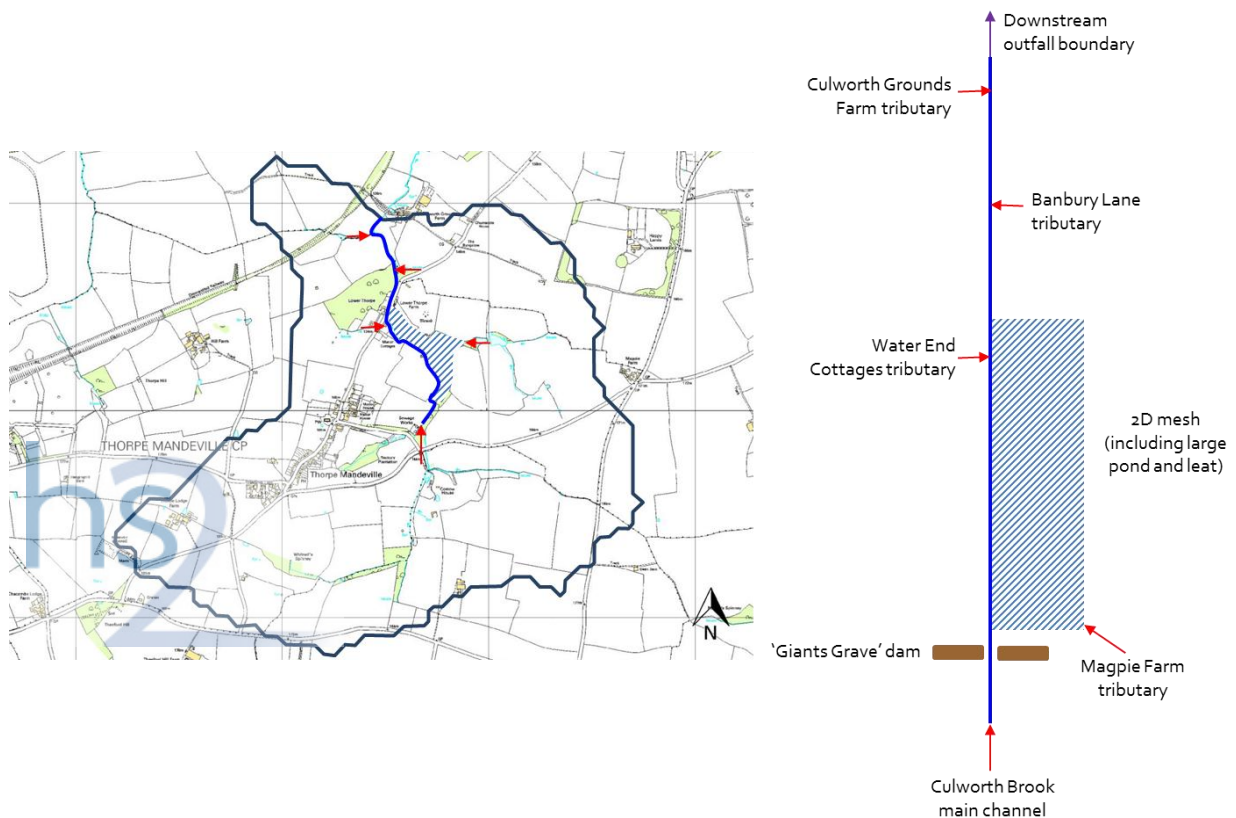


3 Baseline hydraulic modelling

3.1 Model definition

- 3.1.1 A hydraulic model has been constructed using InfoWorks ICM v3.0.3. The model utilises the one-dimensional and two-dimensional capabilities of InfoWorks ICM. The topography of the model is based upon 20cm resolution LiDAR data.
- 3.1.2 The purpose of the hydraulic model is to confirm the existing hydrology and predicted floodplain extent of this reach of the Culworth Brook to inform the design and the flood risk assessment.
- 3.1.3 A one-dimensional model of the main channel of the Culworth Brook was defined from the upstream boundary (close to Thorpe Mandeville Sewage Treatment Works) to the existing culvert beneath the access track to Culworth Grounds Farm. A schematic of the model is shown in Figure 10. Detailed channel surveys are not available, therefore cross-sections were extracted from the LiDAR data at regular intervals.
- 3.1.4 A two-dimensional mesh was defined along the right bank of the Culworth Brook from where the watercourse turns sharply at the 'Giants Grave' dam to the inlet of the culvert beneath Banbury Lane. The mesh extends to the north-east of the existing pond and includes the artificial channel of the Magpie Farm tributary.

Figure 10: Schematic of the hydraulic model for the Culworth Brook



3.2 Model boundaries

- 3.2.1 The upstream boundary of the main channel of the Culworth Brook has been defined as an inflow hydrograph boundary. A two-dimensional inflow boundary was also defined at the upstream extent of the two-dimensional mesh for the Magpie Farm tributary. The tributaries at Water End Cottages, Banbury Lane and Culworth Grounds Farm were defined as inflow hydrograph boundary nodes and the next cross-section from the tributary.
- 3.2.2 ReFH inflow hydrographs were generated for each of the tributary and main channel inflows, as previously discussed in Section 4.2 of this report. Model simulations were undertaken for the 20 year, 100 year, 100 year (including an allowance for climate change) and 1,000 year return periods.

3.3 Roughness coefficients and structural definitions

- 3.3.1 Roughness coefficients have been set using values of Manning's 'n'. The spatial variability of the value of Manning's 'n' has been incorporated by using the definitions provided in the OS mapping. The classifications of roughness coefficients (Manning's 'n') are as follows:
- grass and light vegetation - 0.05;
 - dense vegetation and trees - 0.1;
 - roads - 0.02; and
 - buildings - 1.0.
- 3.3.2 These roughness coefficients have been used in both the one-dimensional channel and the two-dimensional mesh. Within the one-dimensional channel, InfoWorks ICM inserts panels into the cross-section where there is a change in roughness coefficient.
- 3.3.3 Structures such as weirs and sluices were not included in the model as not enough information was available to accurately represent these. There is an existing culvert beneath Banbury Lane within the hamlet of Lower Thorpe that has also not been included in the model. Instead, the cross-sections upstream and downstream of the culvert have been assumed to define the channel throughout this section of the reach.

3.4 Flooding mechanisms

- 3.4.1 Hydraulic modelling results for the simulated return periods were exported from InfoWorks ICM and analysed in MapInfo. For all return periods, flood water remains within the main channel of the Culworth Brook for the first 100m from the upstream boundary. Where the channel has been artificially modified to turn to the west and then north flooding is shown to spill out of the channel and flood overland towards the fish lake, entering the lake along its southern boundary. At the same time the inflow from the Magpie Farm tributary flows towards the fish lake and enters on its north-eastern corner.

- 3.4.2 A proportion of the flow in the Culworth Brook remains within the banks of the main channel and continues to the west of the fish lake. Throughout this section of the reach the channel is well defined and therefore the flow remains within the channel.
- 3.4.3 The dam embankment of the lake retains the majority of the flow that enters the lake. The primary outfall from the lake is into the artificial channel from its north-western corner. For higher return periods (e.g. 100 year) shallow overland flow is predicted to overtop the crest of the embankment.
- 3.4.4 The artificial northern channel is not as well defined as the main channel of the Culworth Brook as bed levels are much closer to surrounding ground levels. A significant proportion of the flow that leaves the fish lake remains in this channel. There are, however, two locations where the left bank of the channel is lower. At these locations flooding is predicted to extend overland towards the main channel of the Culworth Brook to the south.
- 3.4.5 Further to the west, close to the properties at Lower Thorpe, there is a complex arrangement of ponds and channels leading up to a culvert beneath Banbury Lane. Flooding is shown to leave the artificial northern channel and enter the ponds before returning to the main channel of the Culworth Brook upstream of where it would enter the culvert.
- 3.4.6 Downstream of where the outfall of the culvert would be located flow is predominantly within the channel of the Culworth Brook, however, there is some overland flow predicted for all return periods along the right bank of the channel.

3.5 Flood depths

- 3.5.1 Maximum flood depths have been extracted at a number of points throughout the model for all modelled return periods. The location of the results points are shown in Figure 11, and include points within the channel of the Culworth Brook and in the location of overland flow routes.

Figure 11: Results point location plan



3.5.2 The maximum modelled flood depths at each of the results points are provided in Table 3.

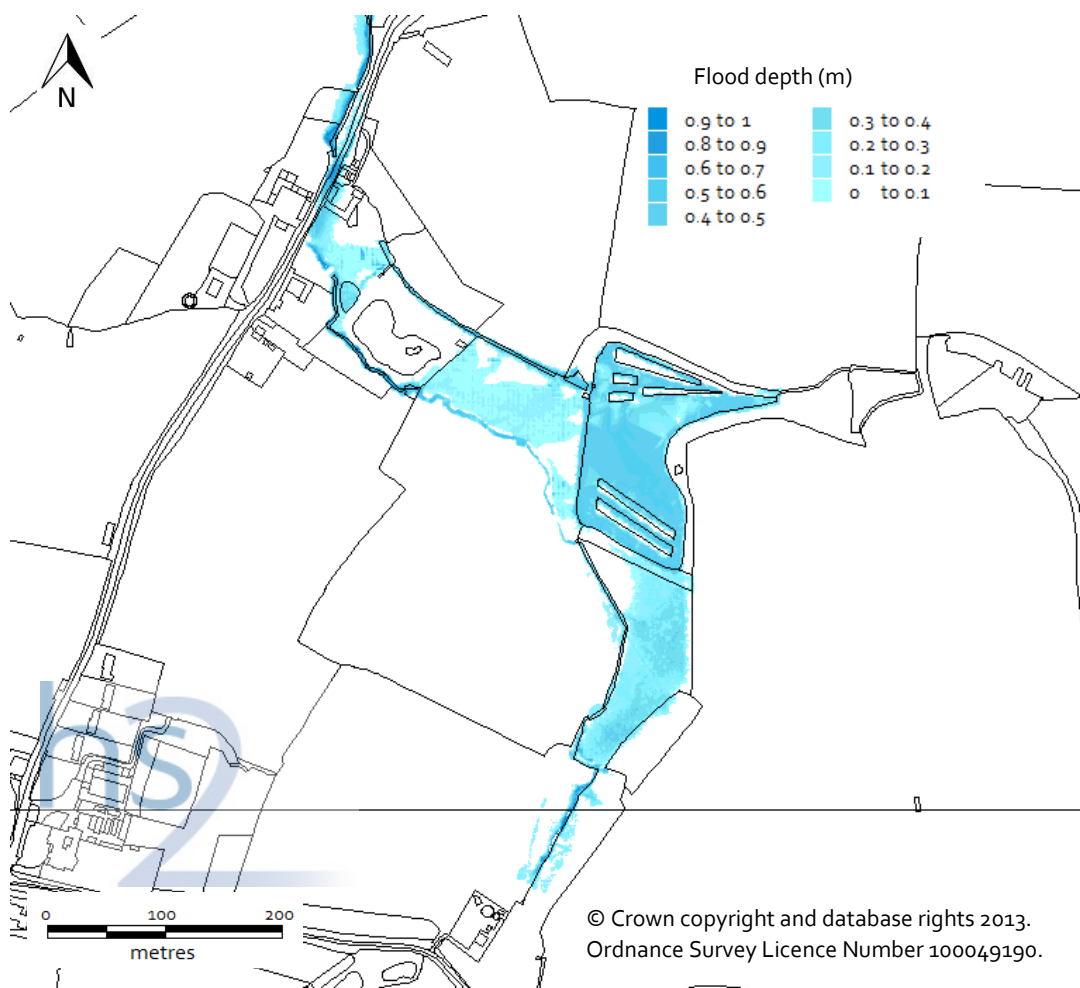
Table 3: Baseline modelled maximum flood depths

Location	Maximum flood depth (m)			
	20 year return period	100 year return period	100 year return period (including climate change)	1,000 year return period
A	0.70	0.70	0.80	0.90
B (two-dimensional)	0.23	0.29	0.32	0.40
C	0.20	0.30	0.30	0.40
D (two-dimensional)	0.07	0.09	0.10	0.13
E (two-dimensional)	0.32	0.38	0.41	0.50
F (two-dimensional)	0.40	0.47	0.50	0.58
G (two-dimensional)	0.08	0.11	0.12	0.16
H (two-dimensional)	0.01	0.02	0.02	0.03
I	0.60	0.70	0.80	1.00
J (two-dimensional)	0.01	0.01	0.01	0.01
K	0.60	0.70	0.80	1.00

3.6 Floodplain extents

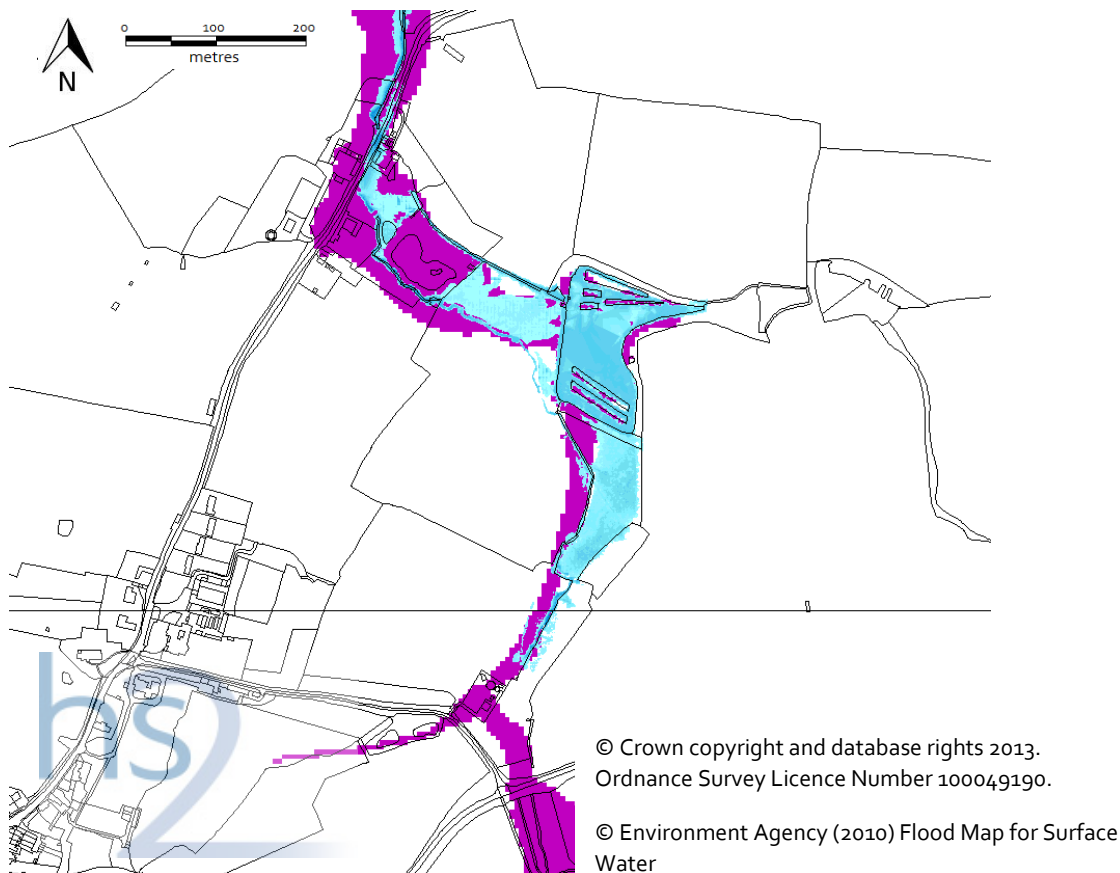
- 3.6.1 Detailed floodplain extents were exported separately for the one-dimensional channel and the two-dimensional mesh. Floodplain extent for the 1,000 year return period event is shown in Figure 12. Floodplain extents for the 20 year and 100 year (plus climate change) return period events are shown on Map WR-05-037 and Map WR-06-037 respectively (Volume 5, Water Resources and Flood Risk Assessment Map Book).

Figure 12: Modelled floodplain extent for 1,000 year return period event



- 3.6.2 For both return period events there is out of channel flooding immediately downstream of the 'Giant's Grave' dam towards the large pond, and also downstream of the pond from the leat to the main channel. There is a break in the floodplain between the large pond and Lower Thorpe where there is a pond. Ground raising activities have been undertaken in this location around the pond.
- 3.6.3 Figure 13 shows a comparison between the 100 year return period floodplain extent of this model and that of the Environment Agency FMfSW and there is a disparity between them. As identified during the baseline assessment of flood risk, the FMfSW does not follow the floor of the valley. The width of predicted overland flow within this section of the reach is also greater than is shown on the FMfSW.

Figure 13: Comparison between 100 year return period flood extent and Environment Agency Flood Map for Surface Water (greater than 0.3m)



3.6.4 There is also a difference between the width of the modelled flood extent and the FMfSW close to the crossing of Banbury Lane. The modelling for the FMfSW did not include the one-dimensional component of the watercourses and as a fairly coarse DTM was used the ground model may not have allowed sufficient capacity in the channel. Caution should be noted in the accuracy of the modelled extent throughout this section of the reach as structures were not included in the one-dimensional channel due to the lack of survey information.

3.7 Flood velocities

3.7.1 Flood velocities are generally low with values between 0.3-1.0m/s in the two-dimensional mesh for the 1,000 year return period event. Highest velocities are seen where flood water overtops the raised banks of the leat and proceeds overland towards the main channel.

3.8 Effect of Proposed Scheme on flood risk

3.8.1 Since the Proposed Scheme will require works within the floodplain, including diversion and culverting of the watercourses, there is potential for the Proposed Scheme to have an effect on the risk of flooding in the area. Potential impacts arise due to the following:

- any construction within areas at risk of flooding will occupy floodplain storage and potentially displace floodwaters;

- linear construction across floodplains, combined with culverting of watercourses could cause obstruction of flow, potentially increasing the risk of flooding upstream of the constriction and reduce the risk of flooding downstream; and
- diversion of watercourses can alter the risk of flooding by changing hydraulic characteristics; for example, straightening and shortening a watercourse can lead to increased flood peaks and hence risk downstream due to reduced conveyance times and reduced energy losses.

- 3.8.2 At the Culworth Brook all culvert crossings will be designed with sufficient capacity to convey the design flood event (1 in 100 years return period (1% annual probability) including an allowance for climate change).
- 3.8.3 The primary source of potential impacts is from the diversion of the watercourse upstream and downstream of the Proposed Scheme. These are subject to detailed design and approval from the Environment Agency and will be supported by detailed hydraulic modelling. Areas have been included within the land required for the Proposed Scheme to accommodate these channel alterations, as well as replacement floodplain storage areas where appropriate.
- 3.8.4 Detailed hydraulic modelling of the Proposed Scheme was therefore not required at this location in order to assess the impact of the development. As this modelling exercise has been used to define baseline flood risk and present absolute flood water levels for the flood risk assessment, sensitivity testing has been undertaken.

3.9 Sensitivity testing

- 3.9.1 The sensitivity of the modelling results in the two-dimensional domain to the value of roughness coefficient was tested by varying the chosen value of Manning's 'n'. By lowering the value of Manning's 'n' within the two-dimensional zone, there was a decrease in the depth of flooding (up to 0.2m difference). The Manning's 'n' values that have been chosen are deemed to be appropriate based on published information and this scale of decrease does not affect the assessment of flood risk to the Proposed Scheme. This testing has, however, shown that the values of roughness chosen for the floodplain do have an impact on flood water levels.

4 Conclusions

- 4.1.1 Sufficient baseline information on flood risk was not available for the crossing of the Culworth Brook at Lower Thorpe to support the flood risk assessment. No existing hydraulic model was available for this watercourse and therefore a one-dimensional-two-dimensional linked hydraulic model has been constructed in InfoWorks ICM.
- 4.1.2 Four flood events have been modelled: the 20 year return period, the 100 year return period, the 100 year return period with allowance for climate change, and the 1,000 year return period flood events.
- 4.1.3 The modelling clarifies that the primary flood mechanism upstream of the Proposed Scheme is predominantly overland flow within the valley of the historic watercourse. The current channel has been artificially straightened due to the construction of a large pond. This area of flooding is different from the extent of the Environment Agency FMfSW. It is recommended that the modelled floodplain extent be used as the baseline dataset in this location.
- 4.1.4 The modelling shows that for all events up to and including the 1,000 year return period storm rainfall, there is a significant amount of shallow out-of-bank flow upstream of the proposed crossing into the large pond. A relatively small proportion of the flow remains within the channel until downstream of the large pond. Flooding has been shown to extend overland between the outfall of the large pond and the main channel of the Culworth Brook.
- 4.1.5 The modelling has also confirmed the flood mechanisms downstream of the large pond, although the culvert beneath Banbury Lane has not been included in the model and therefore the extent of flooding in this area may not be representative.
- 4.1.6 The model is predominantly based on a 20cm LiDAR DTM. The accuracy of the model is considered sufficient to provide the information required at this stage of the project. The model results should not be used for any purpose other than those specified in this report.

5 Assumptions and limitations

Hydrology

- 5.1.1 Flow estimation follows the guidance within the FEH in conjunction with the latest guidance on its use provided by the Environment Agency.
- 5.1.2 Catchment descriptors have been extracted from the FEH CD ROM (v3) and sensibility checks have been undertaken.
- 5.1.3 Where the catchment area is $<0.5\text{km}^2$ and cannot be defined on the FEH CD ROM (v3), catchment descriptors have been extracted for a larger downstream catchment or from an adjacent small catchment. The catchment area has been defined using the DTM and the DPLBAR has been updated using the FEH equation. Sensibility checks on the donor catchment descriptors have been undertaken and adjusted where necessary.
- 5.1.4 The critical storm duration has been calculated using the FEH equation 6. Validation or calibration of the calculated flows with gauged records has not been carried out.

Use of existing models

- 5.1.5 No existing modelling has been used.

Hydraulic modelling

- 5.1.6 Only the assessment of watercourse flood risk has been presented in this report.

Topography

- 5.1.7 The representation of watercourses and two-dimensional mesh zone has been defined based on the LiDAR DTM only. Cross-sections have been digitised using only the LiDAR data. No channel is cut within the ground model, and therefore the in-channel level represented is actually the water level picked up by the flown LiDAR. No modifications have been made to the ground model to reduce this level to account for in-channel capacity.
- 5.1.8 The alignment of the watercourse is based on the LiDAR data, OS mapping and the Environment Agency DRN.

Model parameters

- 5.1.9 Infiltration losses have not been applied.
- 5.1.10 The upstream and downstream model extents have been located a sufficient distance from the crossing by the Proposed Scheme to provide sufficient length for stability.
- 5.1.11 Hydrological inflows have generally been applied in the model as point inflows, apart from the inflow into the two-dimensional mesh from the Magpie Farm tributary.

Structures

- 5.1.12 A site familiarisation visit was undertaken in December 2012, however access was not permitted to the entire reach of the Culworth Brook within the catchment.

- 5.1.13 Detailed survey of structures was not obtained for this study and therefore no structures were included within the model.

Post-processing of results

- 5.1.14 The methodology adopted in the processing of flood outlines for one-dimensional only models may be different to that used in producing the outlines for the Environment Agency Flood Zone Maps. This may account for any discrepancies between the two outlines rather than indicate differences in the model results.

Validation

- 5.1.15 Limited sensitivity testing of floodplain roughness has been carried out to confirm values used within the project. Further, full sensitivity analysis on all roughness parameters and boundaries will be undertaken as part of detailed modelling.
- 5.1.16 Sensibility checks of general flood mechanisms, including flow over the roads within the study area, has been undertaken based on available LiDAR information and aerial photography.

6 References

English Heritage (1982), *Thorpe Mandeville', An Inventory of the Historical Monuments in the County of Northamptonshire, Volume 4: Archaeological sites in South-West Northamptonshire* (1982), pp. 145-148. URL: <http://www.british-history.ac.uk/report.aspx?compid=126588>; Accessed: August 2013

Institute of Hydrology (1999), *Flood Estimation Handbook*.